On Some Issues of United States Tornado Climatology

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ABSTRACT

A continuing problem in dealing with climatological data concerning tornadoes in the United States is the validity of the quantitative information contained in the various available data bases. Two aspects of tornado data are discussed: the F-scale rating and the occurrence of very long path length events. The argument is advanced that the F-scale is more properly thought of as a damage scale than as an intensity scale. Failing to recognize this leads to confusion and controversy regarding the F-scale ratings assigned to events in the data base.

Changing perceptions of tornadoes have led to some questions concerning the actual frequency of very long path lengths, on the order of 100 statute miles (160.9 km) or more. Evidence is presented that at least some of the events classified as having long tracks are most likely the result of misinterpreting the results of a series of short-path tornadoes, produced by a single supercell thunderstorm.

Some discussion is presented concerning the implications of the problems with the data. Since the climatological record is of both meteorological and societal concern, some alternatives are considered, but no hard conclusions can be drawn without considerable further effort.

1. Introduction

Much has been written recently about the climatology of tornadoes in the United States (e.g., Kelly et al., 1978; Schaefer et al., 1980; Tecson et al., 1982). In most of these references, some concern is expressed about the reliability of the data. Since much of the information about tornadoes comes from relatively untrained witnesses, with only a few, special events being subjected to a careful on-site analysis by trained specialists, there is ample reason to suspect the more quantitative aspects of the data base. The FPP rating system (see Fujita and Pearson, 1973) has been recognized widely as a useful means of establishing some measure of tornado characteristics. Basically, the FPP rating system is composed of the F-scale (purported to be an intensity rating scale) and the two P-scales (one [P_L] for path length and one [P_W] for path width). The reader is referred to Fujita and Pearson (1973) for details. In essence, tornado intensity and track characteristics are estimated and FPP num- bers assigned according to the category in which the estimates fall.

At least three major efforts have been undertaken in the last decade to assign plausible FPP ratings to as many reported tornadoes as possible. The three major projects are those by the University of Chicago (Abbey and Fujita, 1979), by the National Severe Storms Forecast Center (Kelly et al., 1978), and most recently by an individual (Mr. T. P. Grazulis—see Grazulis and Abbey, 1983). Interestingly, all three of these have been supported by the U.S. Nuclear Regulatory Commission, with the stated goal of that organization being to provide improved tornado climatology data upon which to base their regulatory decisions.

Although this short note hardly can address all of the potential questions associated with the tornado climatology data, there are some issues which have not always been given the attention they deserve in the formal literature. We propose to examine these in light of continuing research into tornadoes and to consider the continuing problem of assigning an FPP rating to tornado events.

2. The F-scale dilemma

Perhaps no issue of tornado climatology creates more heated discussion than the F-scale rating assigned to particular events. A related issue is the viability of the windspeed estimates assigned to each F-scale category (in analogy with the Beaufort wind scale). For instance, Minor et al. (1977) have questioned the validity of the wind speed estimates assigned to the F-scale ratings whenever the wind speed exceeds 125 mph (56 m s^{-1}). It is generally agreed that wind-speed assignments in the upper F-categories are extrapolated or estimated, since the highest direct measurement of tornadic winds by anemometer is only 151 mph (67.5 m s^{-1}—see Fujita, 1981). Further, as pointed out in Doswell (1985), whenever a structure is totally destroyed, the estimates

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can represent only a lower bound to the windspeed. Since an F-rating is determined by the maximum observed point damage anywhere within the total path of the tornado, a single occurrence of a particular damage level then characterizes the whole path. The DAPPLE method (Abbey and Fujita, 1975) was created in part to address this problem, but the intensity distribution along and across a tornado's path certainly may vary rather widely from one event to the next (Schaefer et al., 1986). Only a careful survey could reveal such details, but surveys normally are reserved for unusually noteworthy events, which probably have a bias for high intensity tornadoes. Perhaps most disturbing is the recognition that tornadoes occurring in open country do not damage anything by which an F-scale estimate can be made (Fig. 1). Any cursory examination of F-ratings shows a clear bias: tornadoes that strike a populated area are much more likely to have a high F-rating than those that remain in open country (Schaefer and Galway, 1982).

a. Damage vs intensity

At the core of most of these problems with the F-scale rating is the implicit assumption that damage and intensity are equivalent. We believe this to be a flawed assumption. Damage depends on the nature of the object receiving damage, even for equal wind speeds. Hence, it seems evident to us that *the F-scale is a damage scale, not an intensity (or windspeed) scale.* While it is clear that damage and wind speed are not unrelated (Schaefer et al., 1986), it is just as clear that the relationship cannot be a simple one (see Reynolds, 1971).

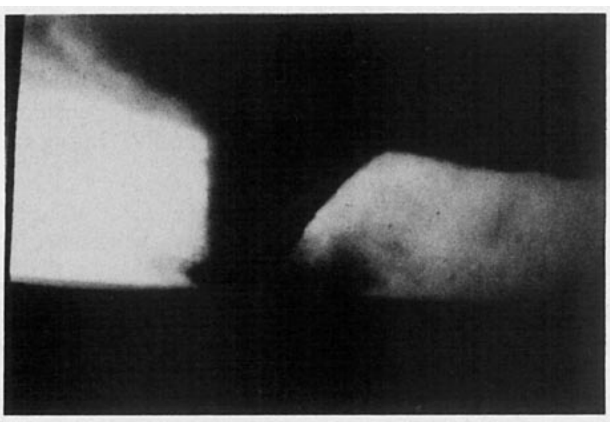


FIG. 1. Tornado near Seymour, TX on 10 April 1979 (NSSL Storm Intercept Project photo). This tornado was from the same storm which produced the Wichita Falls, TX tornado about one hour after this tornado. Originally classified an F0 downburst, based on an aerial survey by an experienced aerial survey crew, the rating and classification of this event was changed later to an F2 tornado, based on broken telephone poles. The tornado remained in open country through most of its 11 mile path. Later photogrammetric analysis of NSSL tornado movies indicated windspeeds of 90 m s^{-1} (Lee, 1981), which exceeds the threshold established for the F2 rating.

If a structure is severely damaged, it may not be possible to determine its structural integrity with sufficient accuracy (especially after the fact) to assess the minimum windspeed needed to cause the observed damage. Further, the nature of the process by which the damage occurred during the event has a powerful control on the extent of the damage. Structures hit by flying debris behave differently than those subjected to wind forces alone. Structures subjected to rapidly fluctuating winds respond differently than those experiencing strong sustained winds. Rural structures tend to be less well-constructed than those built in cities under the attention of building officials. It is difficult, if not impossible at times, to assess these (and other) factors, especially after the event.

It always has been evident that our ability to rate tornado intensity is determined essentially by the number and character of the structures within the tornado path. Heavy damage, to a large extent, certainly implies an intense tornado, but this relation could be violated if the damage was confined to flimsy structures. Also, an intense tornado can not cause heavy damage when it does not hit anything (e.g., as in the case shown in Fig. 1). Further, depending on the circumstances, light damage does not necessarily imply a weak tornado. Strongly engineered structures may survive direct tornado hits of considerable intensity with only relatively modest damage. Moreover, the most intense part of the tornado in space and time (remember that the F-rating is the maximum point value anywhere along the path) may not hit any structure. Finally, a weak tornado may not imply light damage, because even a weak tornado may be sufficient to demolish a weak structure, and/or one with significant engineering flaws.

One recent attempt at an alternative to the F-scale was proposed by Meadon (1976). Rather than six categories, it features 13 gradations of damage. Therefore, the Meadon scheme exacerbates the problem of relating damage to intensity by creating even finer gradations than the F-scale does. Perhaps in part for this reason, the Meadon scale has failed to gain much acceptance. Numerous alternative intensity rating schemes have been suggested (informally). None has ever demonstrated sufficient robustness to make it a viable replacement for the F-scale system, which is already in place and forms the basis for much published material.

b. Nonuniform climatological input

As noted in the references, there are numerous problems with establishing F-ratings for historical tornadoes. Many of the ratings are derived from newspaper accounts, with all the vagaries of newspaper reporting coming into play. Some of those responsible for assigning FPP ratings around the country, now or in the past, have been more diligent than others at seeking details to clarify the rating. There is clear evidence in the data that the tornado climatological record has undergone several changes in philosophy. These and other questions are important, but we do not intend to pursue them all in this note.

Rather, we wish to point out that while the F-scale is essentially a damage scale, the existing F-*ratings* are clearly a *combination* of damage and intensity estimates. That is, a given tornado's F-rating may result from the damage it causes, or it can reflect the estimator's judgement of its intensity, or both.

While the relationship between damage and intensity may be useful, it is certainly possible that many tornadoes have inappropriate F-ratings, perhaps by two categories or more, if *intensity* is being gauged by the F-scale. The quality of the individual estimated F-ratings is quite difficult to assess (even with a detailed restudy of the newspaper accounts, etc.), so the assumption is made implicitly that the errors within the whole data set are essentially random. Under this assumption, the errors tend to cancel, on average, so the averaged values should be a reasonable reflection of the intensity distribution.

Unfortunately, we see some reason to doubt that this is a valid assumption. Assignment of F-scale estimates has been done by a quite limited set of estimators, so an individual estimator can influence the ratings of a large fraction of the events. In fact, whatever subjective criteria an estimator uses could result in a substantial bias to those estimates. More than one estimator is involved, so this creates spatial and temporal inhomogeneities within the data set that will not necessarily cancel out. Thus, many of the temporal and geographical differences in the intensity climatology simply may be the reflection of estimator bias rather than the result of the true variations in intensity. While making all the estimates by a single person would remove some of the inhomogeneities, the resulting data set would still contain systematic biases (those of that single estimator) and there would be no hope of such errors canceling out for the aggregate data base. Consistency is not necessarily an ultimate criterion for assessing the value of the data—consistent error is still error.

3. The reality of very long track tornadoes

Another interesting issue related to the FPP rating climatology is the validity of the estimates of path length and width. Many of the same problems associated with intensity estimation are present in the determination of the track length and width (see Schaefer et al., 1986, for a discussion). Here, we are concerned with the validity of those relatively rare occurrences of very long track (or VLT, an acronym first used by Wilson and Morgan, 1971) tornadoes. In the Wilson and Morgan study, a long track (LT) event was 100–149 statute miles, (160.9–240 km) long, while a VLT tornado was anything longer than that. In the P_L-scale, the highest category, $P_L = 5$, begins at 100 mi (160.9 km). The problem is that it is quite difficult to distinguish between long damage tracks resulting from a single tornado and those caused by a series of short-track tornadoes.

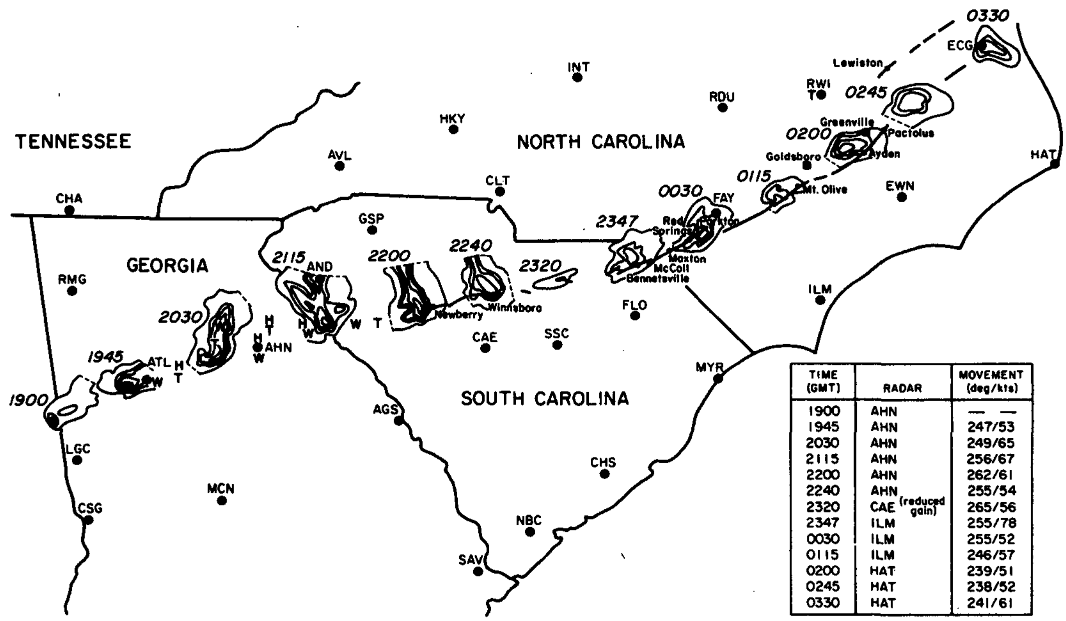
Research has suggested that supercell thunderstorms commonly produce more than one tornado (Fujita, 1963; Rasmussen et al., 1982), and that the tornadoes can be produced in rapid succession, with one still dissipating as the next in the series develops (Burgess et al., 1982; see Fig. 7 in Forbes, 1977 for an example). It is hard to imagine how to go about reconstructing the actual events without a detailed aerial and ground survey and/or trained eyewitnesses. Of course, gaps in the damage path well may be caused by intensity fluctuations (leading to the dubious notion of tornado "skipping") as well as by successive tornadoes. Our experience with tornado observations leads us to question whether some of the documented LT and VLT tornadoes are, indeed, a single tornado. Thus, we consider the following examples.

a. Tri-state versus Carolinas outbreak events

Perhaps the most famous VLT tornado is the so-called "Tri-state" tornado of 18 March 1925, which has the longest track of record to date (Grazulis, 1984; see also Henry, 1925; Chagnon and Semonin, 1966). Chagnon and Semonin (1966) have called attention to the near-coincidence of the tornadic storm and the synoptic scale low in association with which the tornado occurred, speculating that this near-coincidence may have been responsible for its long lifetime.

Recently (28 March 1984), an outbreak of tornadoes in the Carolinas included a series of tornadoes along the extended track of a single supercell storm (Fig. 2). With the more extensive surface data available in 1984, it is possible to see that a major mesoscale cyclone formed near the original large scale cyclone, and grew in intensity and size until it dominated the preexisting large scale cyclone (Fig. 3). While we cannot ascertain the details of the Tri-state storm's large scale evolution, one can surmise that these two events are similar, at least superficially. The Chagnon and Semonin argument about the location of the supercell storm near the center of the large-scale cyclone could be applied to explain the long track of damage. However, we know that the damage track in the 1984 event was indeed the result of a series of short-track tornadoes instead of one long-track storm. It is easy to imagine that those doing the post-event survey of the Tri-state storm, with less extensive data and without today's knowledge of tornadoes to guide the survey, might mistake a similar series of tornadoes for the track of a single tornado.

In the Wilson and Morgan (1971) study, covering all tornadoes from 1916 through 1969, there were 51 events with path lengths between 100 and 149 mi (161 and 240 km, respectively), and 28 with path lengths exceeding 149 statute miles. Together, these yield an



TIME (GMT)	RADAR	MOVEMENT (deg/kts)
1900	AHN	— —
1945	AHN	247/53
2030	AHN	249/65
2115	AHN	256/67
2200	AHN	262/61
2240	AHN	255/54
2320	CAE (reduced gain)	265/56
2347	ILM	255/78
0030	ILM	255/52
0115	ILM	246/57
0200	HAT	239/51
0245	HAT	238/52
0330	HAT	241/61

FIG. 2. Track of the supercell storm responsible for the majority of the 28 March 1984 tornado outbreak. Data are from the indicated radars, with contours based on National Weather Service intensity levels (VIP = 2, 3, 4, 5 and 6). Letters H, W, T, and line segments indicate reports of hail, wind, short-track, and longer-track tornadoes, respectively. Note that the tornadoes near Lewiston, NC are from a different storm.

annual frequency of 1.46 yr^{-1}. In Twisdale's (1982) "unscreened" sample for the period 1950–78, there were 28 tornadoes having a rating of P_L5, giving an annual frequency of 0.96 yr^{-1}. Making the plausible assumption that LT and VLT tornadoes are among the most likely events to be reported in a given year, one expects that they are most likely to have been missed in earlier years, rather than in later years. Hence, the annual frequency should be increasing, rather than decreasing. The reported decrease in long-track tornado frequency is accompanied by an *increase* in the average annual tornado (all types) frequency from 303 yr^{-1} to 462 yr^{-1}, with much of the increase almost certainly attributable to increased reporting of weak, short-track events (Schaefer et al., 1980).

While we cannot prove that the decrease in reports of long-track tornadoes is fallacious, we see no meteorological evidence to support a conclusion that VLT

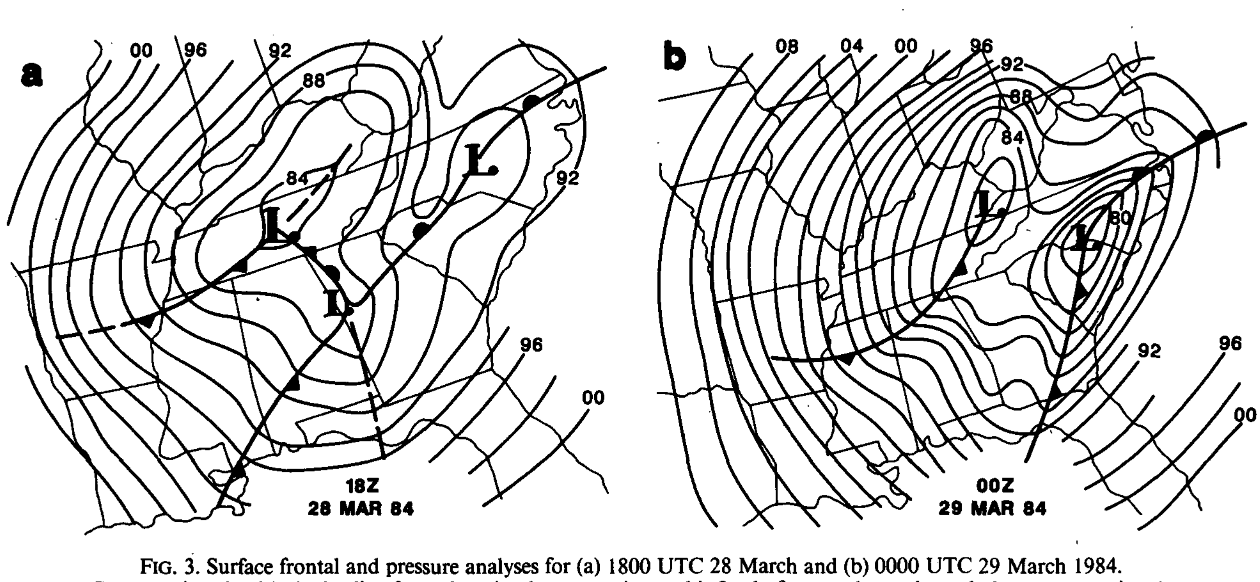


FIG. 3. Surface frontal and pressure analyses for (a) 1800 UTC 28 March and (b) 0000 UTC 29 March 1984. Pressures in mb with the leading 9 or 10 omitted; contour interval is 2 mb; front and trough symbols are conventional.

tornadoes are becoming less frequent. Thus, we find it easier to believe that the Tri-state tornado is misclassified than to accept the observed trend as valid.

b. The Salina event

Tornado track lengths can be classified incorrectly even in the recent past. For example, a tornado outbreak occurred on 25 September 1973 which included several reported long track tornadoes, and one which is described in *Storm Data* as having "skipped along a 138 mile [222 km] path in Kansas". This storm was studied extensively by Zipser (1976), who analyzed film collected from eyewitnesses. Based on his analysis, Zipser concluded that "The total number of tornadoes is unknown. . . . [but] photographic evidence confirms the existence of many discrete tornadoes within a series." We have seen the films and agree that there can be no doubt that this was a series event.

c. The Woodward event

Another well-known VLT event is the tornado which struck Woodward, Oklahoma, on 9 April 1947 (see Asp, 1947). It is listed as one continuous track with a path length of 221 statute miles (356 km—the longest ever recorded in the southern Great Plains). Recent re-investigation of this storm by one of us (DWB) has shown that the event was composed of a tornado family with at least six members (see Fig. 4). The longest member (tornado 2) is reasonably well-documented to have been continuous for 98 mi, perhaps longer if the dashed portion in the Texas Panhandle is added. The lack of structures along that portion of the path renders it impossible to determine damage path continuity for that segment. While the study of past events can never be conclusive, it appears likely that this VLT tornado, like many others, was in reality one moderately long-track tornado and a series of short-path tornadoes.

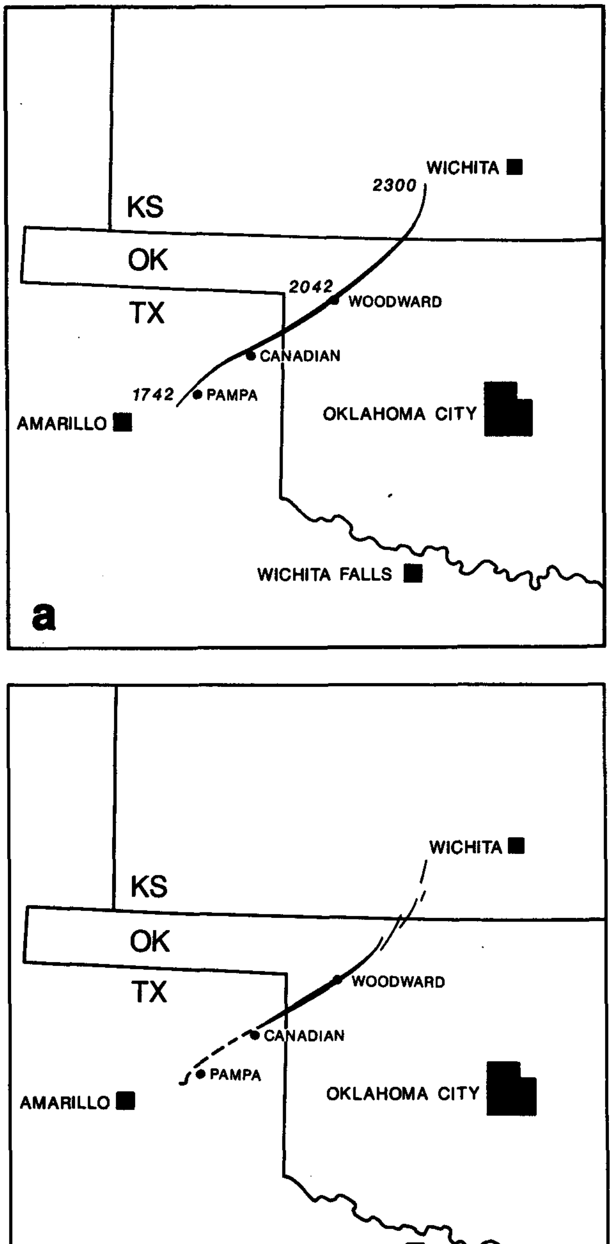


FIG. 4. Path of the 9 April 1947 tornado which struck Woodward, OK, (a) as originally classified, and (b) as reclassified, based on a recent review of the data. Tornado occurrence times shown in (a) are in Central Standard Time. The dashed segment in (b) corresponds to what was in 1947, and still is, a very sparsely populated region within which path continuity cannot be determined definitively.

4. Discussion

We have raised some questions about the F-scale ratings and about the path length estimates. Regarding the F-scale rating, we have tried to emphasize the distinction between damage and intensity, suggesting that *the F-scale is more accurately described as a damage scale than as an intensity scale.* While it is possible to assume some relationship between damage and intensity, the information necessary to assign an intensity rating is not limited to damage. We believe that while many in the meteorological community understand this distinction and implicitly account for it in using the data, it is likely that many nonmeteorologists are unaware of this subtlety. If one must make decisions requiring quantitative knowledge of the climatological distribution of tornado intensity (e.g., see Schaefer et al., 1986), it is risky to accept the F-ratings without qualification for this purpose. To employ the F-scale ratings, one must recognize *explicitly* that they are based predominantly (but not entirely) on damage, which is not equivalent to intensity. Moreover, there is no uniformity across the country about what (and how) other information, if any, is used to assign F-scale ratings. The result is a markedly inhomogeneous dataset upon which to base scientific conclusions.

There are several options for dealing with the F-scale dilemma, other than maintaining the status quo. One alternative is simply to assume that the F-scale is a damage scale, not an intensity scale. This implies, for example, that a tornado causing no damage is given no rating, in the spirit of minimum assumptions proposed by Schaefer et al. (1986). Further, it removes the problem of having to know the engineering data for a structure in advance of its being struck: if a house is swept off its foundation, that is F5 damage by *definition,* with no implication of the windspeeds needed to accomplish the observed damage. We suspect that many people would be unhappy with this option, perhaps because in spite of our implicit understanding to the contrary, many of us are accustomed to accepting some rough equivalence between damage and intensity. It also defeats the original purpose for having the F-scale, which is to provide a climatology of tornadoes in different *intensity* categories.

A second alternative is to make an effort to keep the F-scale rating as an intensity estimate by allowing more information than the observed damage to influence the rating, but in a standardized, scientifically-based way. For example, storm chasers have long been accustomed to blending in visual information about the tornado (including film footage suitable for photogrammetric analysis) and its parent storm with survey data, to produce windspeed estimates. The basic problem with using such additional information sources for F-scale estimates is that they all suffer from the same problem that damage information has: there does not appear to be any feasible and universally applicable means of obtaining such information, much less translating it into intensity estimates. Even careful engineering analysis done with prior knowledge of construction details (an information source only rarely available) suffers from considerable uncertainty in trying to relate damage to windspeed (intensity). Thus, it certainly appears that this alternative also has some unattractive aspects.

A third possibility is to limit the rating of tornadoes to those events that have been documented thoroughly in the meteorological and engineering literature. This alternative is a more stringent version of the first choice we presented. Its main value is in scientific and engineering efforts attempting to relate damage to intensity, rather than in dealing with the problem of establishing a climatology. In fact, we have learned of an effort to collect such a database (Minor, personal communication); i.e., one limited to reasonably well-documented tornado events. However, such an approach fails to address the larger problem of tornado climatology.

Our final alternative may be the most practical. The basic problem in rating tornadoes is the credibility of the source, so it is logical to add data about the rating source to the overall data base. That is, *one would identify the source for the rating along with the report.* It makes a considerable difference in interpreting the rating, for instance, if one knows whether or not an on-site survey was conducted. Grazulis (personal communication) has indicated that some tornadoes causing no damage are given "default" ratings in the NSSFC and DAPPLE datasets, which vary from one rater to another. It would be useful to know if a given rating was established by default, by information gleaned from newspaper clippings, by storm chaser input, or whatever. This would give the users of the ratings critical information when they attempt to employ the data to serve specific ends.

In addition to the F-ratings, the path length problem is another example of how our changing perceptions of tornadoes have resulted in a dilemma. Research constantly is increasing our awareness of how tornadoes behave and we no longer regard even the rather rare VLT tornado events with the same scientific credibility we once did. However, our constantly changing scientific perception is not well reflected in standardized reporting procedures. For example, the National Weather Service procedure (as documented in the Weather Service Operations Manual, Ch. F-42) for determining path length states that tornado damage tracks with gaps of less than five statute miles should be combined into a single, "skipping" path. It should be noted that this procedure, until recently, accepted up to 10 mi gaps in a "continuous, but skipping" tornado.

Given these problems, how does the scientific community use the existing tornado climatology of FPP ratings? Unfortunately, it appears to be a real challenge to reconstruct past events in light of changing perceptions. The situation is quite unlike some other climatological data, such as temperature or precipitation. While the spatial and temporal resolution of temperature records may not be suitable for all purposes, there is not much room for ambiguity in a temperature observation. The tornado climatological data provide the basis for application of the scientific method to such things as forecasting tornadoes, establishing regional insurance rates, and formulating construction code requirements. Ambiguities of the sort we have been describing raise the specter (also noted by Reynolds, 1971) of making erroneous conclusions when based on the climatological record.

The situation is not entirely hopeless, however. For instance, Colquhoun and Shepherd (1985) have found that the F-scale ratings seem to confirm a plausible relationship to such environmental factors as wind shear. In effect, the sounding data are independent information from the F-scale ratings, so if the environments associated with different F-ratings are statistically separable, there is some reason to believe that the ratings have some statistical validity. However, one should not interpret this to mean that errors in the data tend to cancel out. The conclusions of Colquhoun and Shepherd do not preclude the presence of significant geographical and temporal biases in the F-scale data, since their dataset was limited.

We have indicated a few of the myriad reasons to regard the quantitative aspects of the climatological tornado record with considerable skepticism. Indeed, some of what we (and our references) have said applies to non-tornadic events (Kelly et al., 1985), as well. Unfortunately, the responsibility for developing our climatological database for severe convection falls on the shoulders of a relatively few, generally overburdened National Weather Service staff, working with a shrinking resource base. Further, their training in the intricacies of interpreting the available data for the purpose of rating severe storm events is woefully inadequate.

If the community as a whole wishes to have the best possible information about severe weather events, this situation should not continue uncorrected. *Either the community gives adequate formal recognition to the limitations of the climatology, or the collection of the data must be enhanced with staffing, training, and resources to do the job in a manner appropriate for the uses to which the data are applied.* The latter choice means that interested members of the meteorological and engineering communities must contribute to developing an acceptable and feasible strategy for obtaining and interpreting the data. We do not pretend to know how to solve all the problems we have identified, but in the absence of those solutions, we believe it important to use the FPP ratings with the appropriate caveats in mind.

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